Flood Damage Reduction Costs and Benefits

This attachment provides an overview of the flood damage reduction costs and benefits of this Proposal.

Reduced Local Flooding

The Los Angeles County Flood Control District (District) operates and maintains the Santa Anita Dam (Dam) and Santa Anita Debris Basin (Debris Basin) as part of its flood control network for the Greater Los Angeles Region. Both the Dam and Debris Basin are under the jurisdiction of the State Department of Water Resources Division of Safety of Dams (DSOD) and are required to withstand a Maximum Credible Earthquake (MCE) and to safely pass, through their spillways, the Probable Maximum Flood (PMF).

The MCE is the largest earthquake that is expected to occur based on geologic analysis of a specific earthquake fault. The PMF is the expected stormwater runoff resulting from the most intense storm event that is considered possible to occur over a specific watershed (considered to be a once in 10,000 year event). If a dam cannot withstand the MCE, its structure could fail suddenly releasing the water stored behind it. If the dam is empty or only partially full at the time of the earthquake, subsequent storms could fill the reservoir behind the dam and then suddenly be released. If a dam cannot pass the PMF, large storm events can overtop the dam and erode the abutments or undermine the dam foundation resulting in failure of the dam and sudden release of the reservoir.

The State requires dam owners to prepare inundation maps (See Appendix 7-A) delineating the areas of flooding based on a sudden dam failure with a full reservoir. The Dam's inundation zone is provided in Figure 7.1. This area encompasses 14,676 parcels within the Cities of Arcadia, Monrovia, Temple City, El Monte, and Unincorporated Los Angeles County. The inundation zone was developed assuming that a rapid failure of the Dam would occur when the reservoir is full. The inundation zone includes 12 schools (six elementary, four middle, and two high schools), two fire stations, one City Hall and two libraries. In addition, there are over 12,000 single-family residences, over 1,300 multi-family residences, 686 commercial buildings, 181 industrial buildings, and 43 institutional buildings. The approximate replacement value for these existing building and their contents is $2.844 billion dollars based on 2003 Los Angeles County Assessor Information. Additional infrastructure within the inundation zone which would be damaged, such as utilities, roads, including the 210 freeway, bridges and flood control structures are not included in the valuation. Loss of life, reduced commerce, and reduced quality of life are also not accounted for in this analysis.

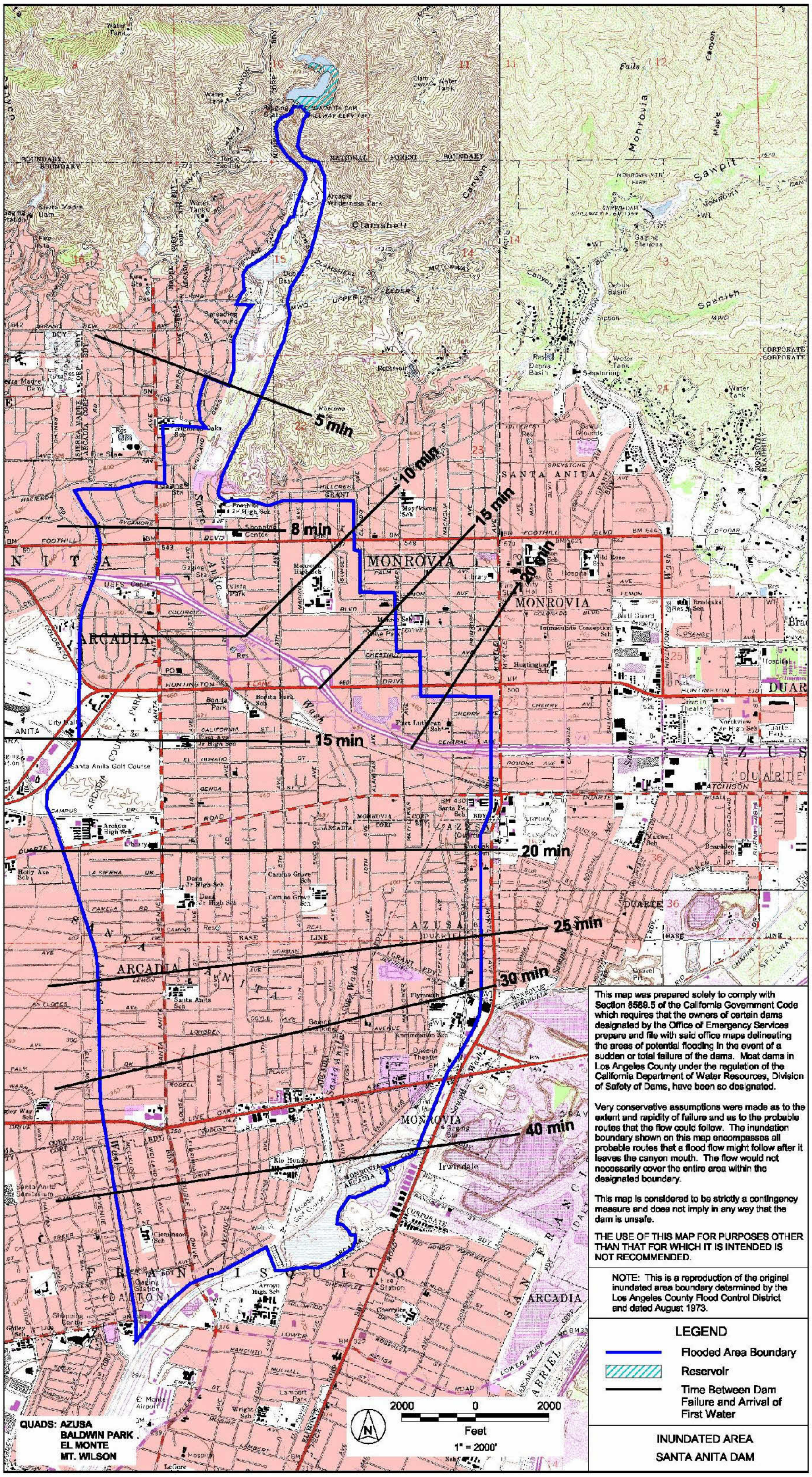


Figure 7.1 – Santa Anita Inundation Map

The Debris Basin's inundation zone (see Appendix 7-A) is provided in Figure 7.2. This area encompasses approximately 65 parcels within the City of Arcadia. The inundation zone includes 65 single-family residences. The approximate replacement value for these existing buildings and their contents is $14.7 million dollars based on 2003 Los Angeles County Assessor Information. Additional infrastructure within the inundation zone, which would be damaged, includes utilities, roads, and the Santa Anita Spreading Grounds. The inundation zone of the Debris Basin is completely within the inundation zone of the Dam.

This Project will modify the District's flood control and water conservation facilities to improve management of stormwater runoff to increase safety and reduce the potential for flood damage to downstream communities within the inundation zones that could result from a large seismic or storm event.

Table 7.1: Benefits Summary

Type of Benefit	Assessment Level	Beneficiaries
Reduced Flood Damage to structures from Local Flooding	Quantitative	Local
Reduced flood damage to other infrastructure (utilities, roads, including the 210 freeway, bridges, channels and storm drains,) Reduced impacts to commerce and quality of life	Not Quantified due to uncertainty of costs Qualitative	Local / Regional Local / Regional

Distribution of Project Benefits and Identification of Beneficiaries

The following table summarizes the Project's beneficiaries. The Project will benefit local residents by improving public safety, reducing the potential for local flooding, reducing flood damage, and ensuring the quality of life.

Table 7.2: Project Beneficiaries Summary

Local	Regional	Statewide
Local Residents	Greater Los Angeles Region	NA

Project Benefits Timeline Description

The full Project benefits would be realized beginning in 2014.

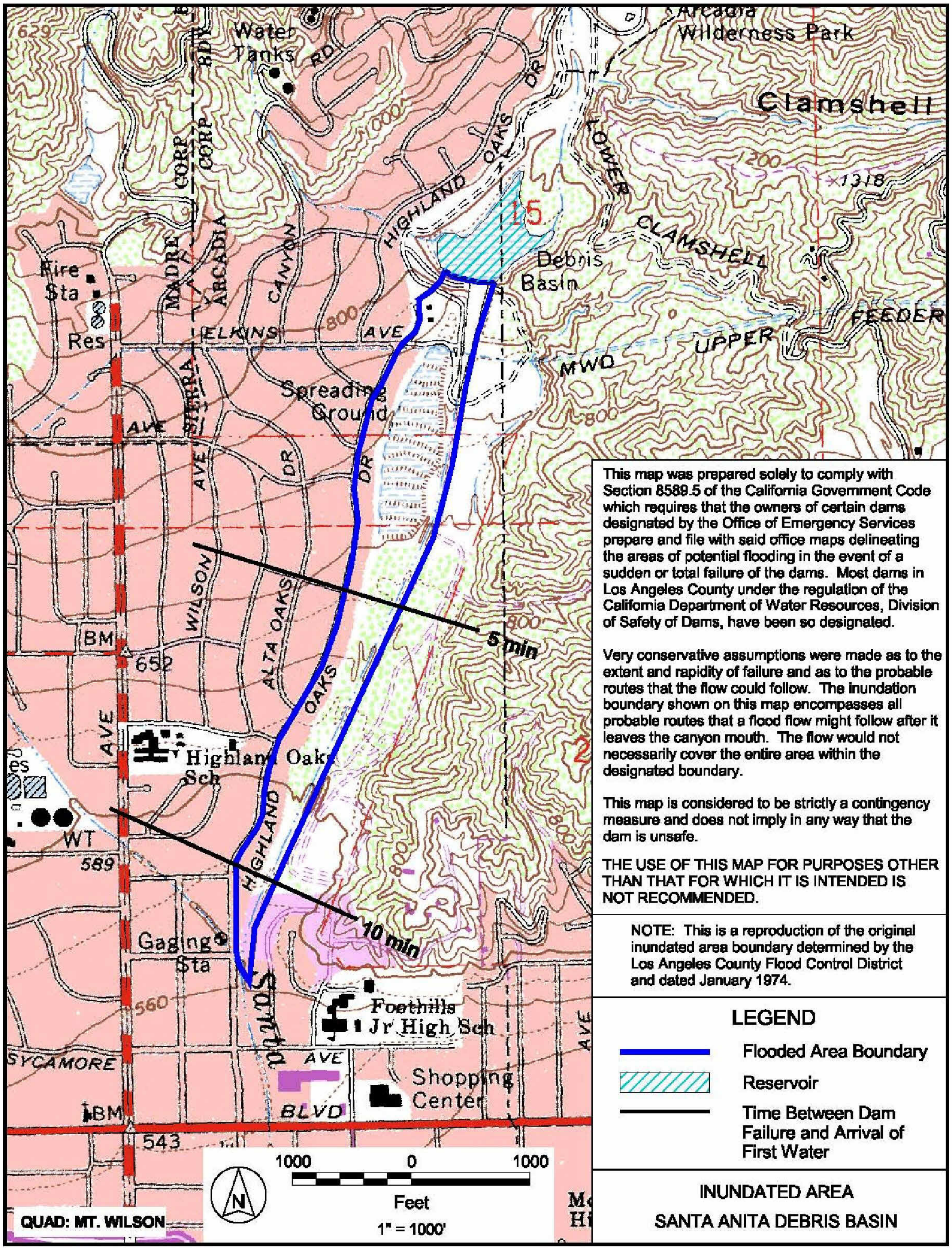


Figure 7.2 – Santa Anita Debris Basin Inundation Map

Uncertainty of Benefits

Without the Project, two types of events could result in significant flood damage to the communities located below the Project; a large storm event or a major earthquake. Analyses of both are discussed below. The Project flood damage reduction benefits are significantly higher based on the FRAM model analyzing a large storm event than they are based on a major earthquake. These benefits have been determined to be $2.5 Billion the resulting BCA is 63.0 (see Appendix 7-B). However, because this application is for grant funding only eligible to Stormwater Flood Management Projects that also address seismic safety issues, only the project benefits based on a major earthquake are reported for the Flood Damage Reduction Costs and Benefits. Based on this, the flood damage reduction benefits reported are much lower than the actual benefits achieved by the project.

In addition, there is an uncertainty in the flood damage reduction benefits since we did not monetize the Project benefits of reduced impacts to non-building infrastructure, commerce, or quality of life. Because these qualitative benefits were not included, the Flood Damage reduction benefits reported are lower than the actual benefits achieved by the Project.

Description of any adverse effects

Any potential adverse effects from this Project would occur during construction and will be mitigated In accordance with the environmental documents and permits.

The “Without Project” Baseline

As discussed above, without the Project, two types of events would result in significant flood damage to the communities located below the Project; a large storm event or a major earthquake. Appendix 7-C contains hydrologic runs of 2-, 5-, 10-, and 50-year frequency storms.

During a storm event, inflow to the Dam would begin filling the reservoir and dam outflow would occur through the existing sluice gate outlet tunnel and the three valve penstocks, depending on rate of inflow and the resulting height of the reservoir. For the “Without Project” condition, the sluice gate is locked open and valves are removed as a requirement of DSOD to limit the height of the reservoir. Despite these measures, during more intense storms, the inflow into the Dam will exceed the capacity of the outlets, resulting in the reservoir rising. The sluice gate outlet tunnel is at the bottom of the reservoir and is protected with a trash rack; however, the trash rack could easily be blocked or buried with sediment from the uncontrolled watershed above the Dam, resulting in the reservoir level rising even faster. As the reservoir rises, flow will begin going over the spillways. The total capacity of the existing main and auxiliary spillways is 1,376 cfs. This corresponds to a 10-year storm event (a storm that is expected to occur once in 10 years or has a 10 % chance of occurring in any year). If the storm event exceeds the spillway capacity, the Dam will overtop in an uncontrolled manner, which could erode the Dam abutments and undermine the Dam foundation, resulting in a Dam failure and release of the full reservoir behind the Dam. Although a 10-year storm event would result in uncontrolled overtopping of the Dam, the District estimates that uncontrolled overtopping of the Dam during a 50-year storm event or less would result in damage to the abutments but would not result in failure of the Dam. The Santa Anita Wash downstream of the Dam has adequate capacity for the runoff resulting from a 50-year frequency storm. During a greater than 50-year frequency storm the Dam is expected to fail. The area impacted by the resulting flood, shown graphically in figure 7.1, and the projected flood damage is discussed above.

Both the Dam and the Debris Basin are classified as dams and are under the jurisdiction of DSOD. DSOD requires both the Dam and the Debris Basin to be structurally adequate to withstand a MCE (a magnitude 7.5 earthquake on the Sierra Madre Fault). Neither the Dam nor the Debris Basin meets this requirement. As a result of a major seismic event, both the Dam and Debris Basin could fail. Under the “Without Project “ scenario, both the Dam and Debris Basin would likely be empty at the time of an earthquake because DSOD requires the gates to be locked open and the valves removed. Therefore, flood damage would only result if a subsequent storm event occurred after the damaging earthquake and prior to repair. The subsequent storm event is expected to fill the Dam and then the Dam would fail as a result of the prior earthquake damage and the increased forces on the Dam from the reservoir. The inundation area and expected flood damage resulting from failure of the Dam is much greater than that of the Debris Basin; therefore, the Dam analysis will be used to determine the Flood Damage Reduction Costs and Benefits of the Project.

The Dam has been analyzed using a dynamic finite element model, which determined the “safe” long term reservoir elevation is 1231 feet. During a MCE, the Dam would sustain damage and cracking of the structure at locations above 1231 feet. Because the reservoir would be below the elevation of damage, water would not be released through the damaged Dam. If the reservoir is higher when the MCE occurs, the additional reservoir water would impart additional forces on the Dam during the earthquake, resulting in more damage to the Dam. In addition, the reservoir water would flow through the cracked Dam resulting in Dam failure and flooding. DSOD requires the District to implement seismic remediation measures to ensure the ability to discharge reservoir inflows above the “safe” elevation of 1231 feet.

Without the Project, the required seismic remediation will not be implemented and the existing sluice gate outlet and three valve conduits will be relied upon to lower the reservoir. The sluice gate is locked open and the valves are removed. Because the sluice gate outlet is at the bottom of the reservoir, storm inflow from the reservoir, which includes high volumes of sediment, would likely bury the outlet. Sediment removal projects by the District require years to plan, which includes obtaining necessary environmental documents and permits. With a buried sluice outlet, only the three valve penstocks would be available to remove water from the reservoir. They have a capacity of only 633 cfs, which would be 1,000 cfs less than with the sluice gate operational. A major earthquake during or shortly after a 2-year or larger storm event could result in Dam failure. The area impacted by the release of the water in the reservoir during the Dam failure is shown in Figure 7.1. The projected flood damage is discussed above. If the major earthquake were to occur with the reservoir empty, a subsequent storm of less than a 2-year frequency (50% chance of occurring in any year) would bring the reservoir to spillway elevation and the Dam could completely fail. The ability of the District to remediate dam damage prior to the occurrence of a 2-year storm event would be a challenge due to a potentially short timeline.

The "With Project" Analysis

To address the large storm event scenario, the Project proposes to eliminate potential flood damage resulting from a dam failure by constructing a new spillway on the Dam with adequate capacity to safely pass the PMF (26,100 cfs) without overtopping. The PMP is considered a once in 10,000 year event. Armoring measures constructed by the Project protect the abutments from erosion and the Dam from being undermined. The downstream channel has adequate capacity for a 50-year storm event; however, it does not have capacity for the PMF. Therefore, even though the Dam would not fail, some flooding along the channel would occur. This flooding would be significantly less than that due to a dam failure. The PMF flow rate at the Dam is 26,100 cfs, and the downstream channel capacity is 25,000 cfs which would result in limited flooding downstream. Because the PMF flooding flow rate is 6.5 % of the Dam Failure flooding flow rate, we have calculated the flood damages from the PMF as 6.5% of the flood damages resulting from Dam Failure. The FRAM analysis for the storm event is included as Appendix 7-B.

To address a major earthquake scenario, the Project will include the construction of a new outlet tower capable of withstanding the MCE and ensuring the ability to drain the reservoir of any flows above elevation 1230 feet. The outlet tower will extend 50 feet above the bottom of the reservoir and will not be susceptible to blockage by sediment or debris. The new outlet tower will have a 1,000 cfs capacity.

With this Project, a 5-year frequency storm event would be required to raise the reservoir to the spillway level. Because of the high outflow rate of the outlet, the reservoir would be above the "safe" elevation for a shorter period of time than the Without Project scenario. If a major earthquake were to occur during this brief period of time when the reservoir is a spillway level, the Dam could fail. If the Dam were to experience a major earthquake during a period of dry weather, no release of the reservoir would occur. However, if a subsequent 5-year storm event were to occur, the earthquake damaged Dam could then completely fail.

The likelihood of the District to remediate the damage prior to a 5-year storm occurring is much higher than it would be to complete it prior to a 2-year storm event as required under the

"Without Project" condition. If the 5-year storm event were to occur prior to District remediation of the seismic damage and the Dam were to fail, the resulting inundation area and flood damage would be significantly less than that for the "Without Project" condition because the Project will result in a much lower spillway elevation. The new spillway will be at elevation 1270 feet, which is 46 feet lower than the Without Project condition. The lower spillway elevation will result in a much smaller reservoir volume (539 acre-feet versus 1076.5 acre feet). The resulting Flood Damage for buildings and content only is estimated at $1,806,877,500 (in 2003 Dollars).

At the Debris Basin, the Project will result in no damage and no release of reservoir water during a MCE. There is no resulting flood damage. This is a substantial reduction compared to the Without Project condition, which results in significant damage as discussed above. However, because the Dam impacts are much greater during a seismic event, this analysis focuses on the impact of the Dam only, and does not include the Project benefits associated with seismic remediation of the Debris Basin.

Methods used to Estimate With- and Without-Project Conditions

For the seismic analysis, the discussion above demonstrated why the "Without Project" scenario is much more likely to result in release of reservoir water and subsequent flooding as a result of seismic damage to the Dam. Because quantifying the increased frequency is difficult, the calculation of Flood Damage Reduction costs and Benefits does not account for the increased frequency. The calculation only accounts for the differences in the expected amount of damages with a potential to occur following a major seismic event.

Flood Damaged estimated With and Without-Project conditions is based upon the building and content value in the inundation zone that would be impacted if the Dam were to have a complete failure during a seismic event with a return period of 300 years. After the Project, the Dam would still be susceptible to damage during a seismic event with a return period of 300 years, however, as discussed above, the likelihood of storm events that would result in release of water from the earthquake damaged dam is significantly less for the Project condition. This reduction in frequency is not included in the analysis, instead to ensure the model is extremely conservative, only the reduction in damage for failure of the Project Dam at spillway compared to the failure of the Dam at spillway for the Without Project Dam are included.

Big Tujunga Dam is a similar concrete thin-arch dam that was recently retrofitted by the District for the same seismic deficiency and Probable Maximum Precipitation (PMP) deficiency. Big Tujunga Dam's most recent Benefit Cost Analysis, which is located in Appendix 7-D, will be used as a reference for this flood reduction analysis. The seismic return period for failures (Big Tujunga Dam before Project improvements) was calculated to be 300 and that will be used for this flood reduction benefit analysis as a conservative, lower- bound value. However, it must be noted that the return period for failure due to overtopping as a result of an extreme flood event would be lower since overtopping could occur more frequently.

For the purpose of this analysis, the District also assumed 90% damage to buildings within the inundation zone. Nearly all of the buildings would be destroyed if the Dam were to fail suddenly with a full reservoir. However, some buildings at the extreme fringe of the inundation zone may survive with less than complete damage. The damage to buildings is estimated to be $2,559,600,000 (in 2003 Dollars).

Typical building content value is 50% of the building replacement value, which would total $1.422 billion dollars. For the purpose of this proposal, the District assumed a 90% content replacement value to be consistent with the amount of building damage noted above, which would bring this cost to $1,279,800,000 (in 2003 Dollars).

The inundation times range from zero to 40 minutes at the Rio Hondo River. There are no inundation warning alarms in these neighborhoods and few occupants within the zone are likely to react quickly enough to avoid inundation. The Federal Emergency Management Agency (FEMA) Benefit-Cost Analysis Toolkit-Data Derivation manual notes that Casualty Avoided Benefits are generally not applicable except for flash flooding situations. Both Big Tujunga Dam and Santa Anita Dam would fall under the flash flooding requirement; however, the District, in the spirit of this conservative lower-bound type analysis, will assume no Avoided Death benefit.

Table 7.3: Scenario damages and Losses per Dam Failure Event

Building Damages	$2,559,600,000
Contents Damage	$1,279,800,000
Subtotal	$3,839,400,000

These subtotal for damages and losses would be $3,839,400,000. In 2009 dollars, that cost would be $4,492,098,000.

Table 7.4 Annualized Damages and Losses

	Event Damage		Event Benefit ($) (a) - (b)
	(a) Without Project	(b) With Project	
Return Period for Failures	300	300	N/A
Annualized Damages (2009 Dollars)	$14,973,660	$7,486,830	$7,486,830

Table 7.5: Present Value of Expected Annual Damage Benefits

Present Value of Expected Annual Damage Benefits Project: Santa Anita Stormwater Flood Management and Seismic Strengthening Project			
(a)	Expected Annual Damage without Project (1)		$14,973,660
(b)	Expected Annual Damage with Project (1)		$7,486,830
(c)	Expected Annual Damage Benefit	(a) - (b)	$7,486,830
(d)	Present Value Coefficient (2)		15.76
(e)	Present Value Future Benefits	(c) x (d)	$117,992,441

(1) This program assumes no population growth; therefore ,the Estimated Annual Damage will be constant over analysis period

(2) 6% discount rate; 50-year analysis period

Project Benefit Costs Comparison

The total present value of the costs for the Project, along with monetized and qualitative benefits, is provided in Table 7.6.

Table 7.6: Benefit-Cost Analysis Overview

	Present Value (In 2009 Dollars)
Costs – Total Capital and O&M	$33,350,000
Monetizable Benefits	
Water Supply Benefits (Avoided water supply purchases – 518AFY)	$4,883,554
Water Supply Benefits (Avoided Project cost)	$18,284,858
Flood Damage Reduction	$117,992,441
Total Benefits	**$141,160,852**
Qualitative Benefits	**Qualitative Indicator****
Water Supply Benefits (Improved supply reliability)	+
Reduced Impacts to other infrastructure	+
Reduced Impacts to Quality of Life and Commerce	+
Water Supply Benefits (Enhanced Bay-Delta Ecosystem habitat)	+/-

** Magnitude of effect on net benefits

+/- (negligible or unknown)

+ (moderate)

++ (significant)

APPENDIX 7-A

Inundation Maps

LOS ANGELES COUNTY FLOOD CONTROL DISTRICT

MEMORANDUM

TO: Mr. C. F. Eshelby
Hydraulic Division

DATE October 11, 1973

FILE NO. 223.41
Santa Anita Debris Basin
Documentation of Inundated
Area Boundary

FROM: G. L. Barber

Location of Breach

The only possible location of a breach in Santa Anita Debris Basin that would have damaging effects downstream is between the west wall of the spillway and a point 220± feet west of this west wall. This is the only part of the dam west of the spillway with water behind it when the water surface is at spillway elevation. Since the zero freeboard capacity of Santa Anita Wash (25,000 cfs) is much larger than the breach peak (6,400 cfs), a failure at the spillway would cause insignificant inundation downstream. A breach east of the spillway would be impossible as the ground level south of the dam is higher than the spillway.

East Boundary

It is estimated that no flood waters will spread east of Santa Anita Wash because: a) a breach east of the spillway is impossible and b) the large zero freeboard capacity of the wash will contain any water reaching it from the west.

West Boundary

Highland Oaks Avenue is assumed to be the conservative west boundary south to the Sierra Madre Wash confluence with Santa Anita Wash because of the following reasons:

a. The houses on the east side of Highland Oaks Avenue are 20± feet higher than the spreading grounds 800± feet downstream of the dam.

b. From 800± feet downstream of the dam to the confluence, some houses on the east side of Highland Oaks Avenue could get flooded, but the houses on the west side are 8 to 10 feet above the street.

c. A small amount of water will reach the confluence as a result of the 6,400 cfs peak discharge, 3,000 to 3,500 cfs will be taken by the channel, and a great deal will be taken by the spreading grounds.

d. The zero freeboard capacity of Sierra Madre Wash at the confluence is 4,800 cfs which is much larger than the flow spreading overland through the spreading grounds.

Sierra Madre Wash is, therefore, the south boundary.

J. C. Lord
Hydraulics and Hydrology Section
Extension 74243

JCL:dms

Santa Anita Dam Inundation area:

Population Count (2000 Census) 48,400

Parcels within Inundation area: 14,676

Improvement Values (2003 LA County Assessor)

	COUNT	IMPROVEMENT VALUE
Single Family Residential (SFR)	12081	$ 1.967 B
High Density Residential: (HDR)	1326	$ 312 M
Commercial (COM)	686	$ 462 M
Industrial (IND)	181	$ 83 M
Institutional (INST)	43	$ 20 M

Schools:

Elementary	6
Middle	4
High School	2

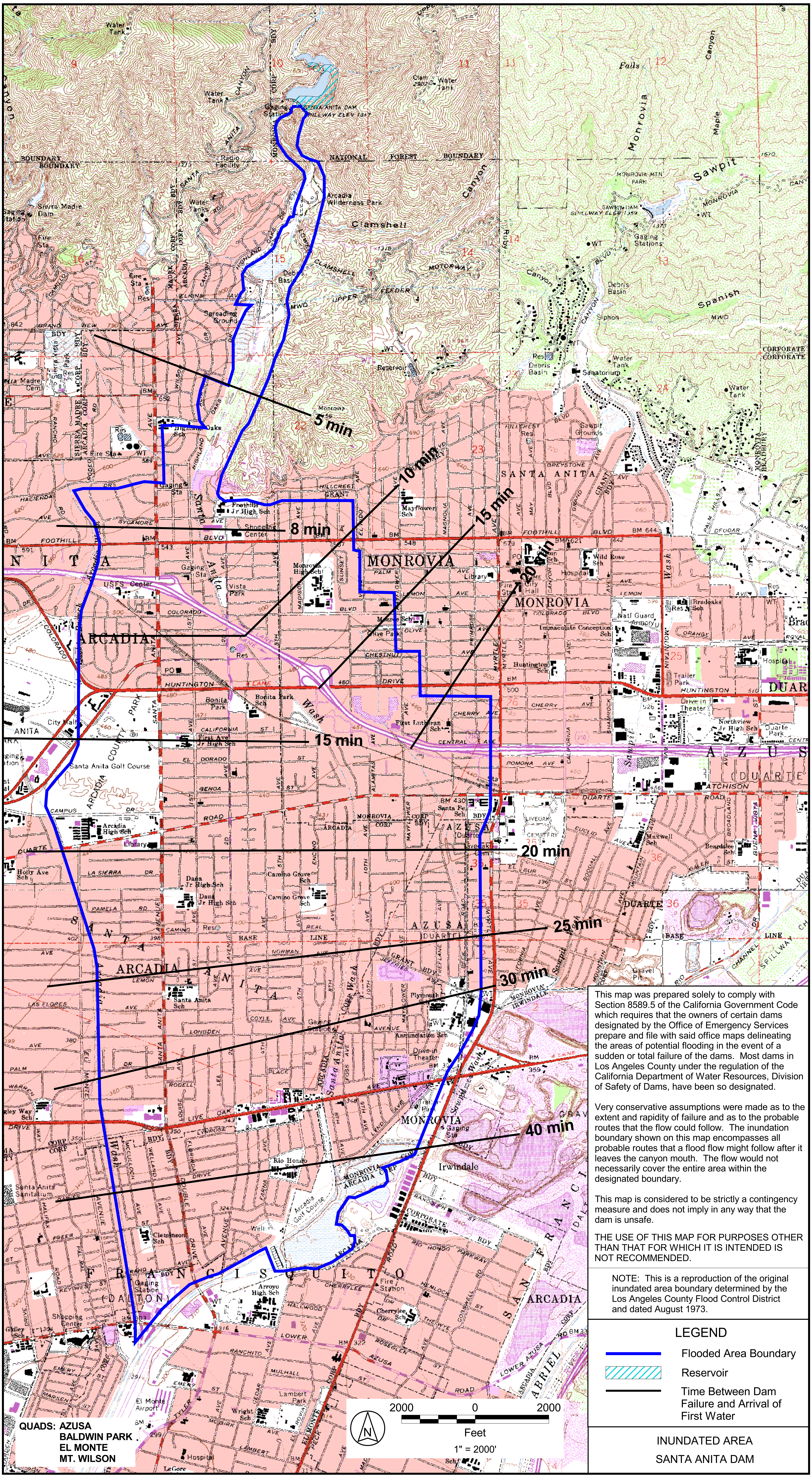
Others:

Libraries:	2
City Hall:	1
Fire Station:	2

The rest are 800/900 Parcels,
Agricultural, LACFCD, &
vacant parcels

Total Improvement Value = $ 2.84 B*

*Summation of parcels categorized as SFR, HDR, COM, IND & INST). Excluded are AGR, vacant, LAFCD & 800/900 parcels.



This map was prepared solely to comply with Section 8589.5 of the California Government Code which requires that the owners of certain dams designated by the Office of Emergency Services prepare and file with said office maps delineating the areas of potential flooding in the event of a sudden or total failure of the dams. Most dams in Los Angeles County under the regulation of the California Department of Water Resources, Division of Safety of Dams, have been so designated.

Very conservative assumptions were made as to the extent and rapidity of failure and as to the probable routes that the flow could follow. The inundation boundary shown on this map encompasses all probable routes that a flood flow might follow after it leaves the canyon mouth. The flow would not necessarily cover the entire area within the designated boundary.

This map is considered to be strictly a contingency measure and does not imply in any way that the dam is unsafe.

THE USE OF THIS MAP FOR PURPOSES OTHER THAN THAT FOR WHICH IT IS INTENDED IS NOT RECOMMENDED.

NOTE: This is a reproduction of the original inundated area boundary determined by the Los Angeles County Flood Control District and dated August 1973.

INUNDATED AREA
SANTA ANITA DAM

LOS ANGELES COUNTY FLOOD CONTROL DISTRICT

MEMORANDUM

TO: Mr. C. F. Eshelby
Hydraulic Division

DATE October 11, 1973

FILE NO. 223.41
Santa Anita Debris Basin
Documentation of Inundated
Area Boundary

FROM: G. L. Barber

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The only possible location of a breach in Santa Anita Debris Basin that would have damaging effects downstream is between the west wall of the spillway and a point 220± feet west of this west wall. This is the only part of the dam west of the spillway with water behind it when the water surface is at spillway elevation. Since the zero freeboard capacity of Santa Anita Wash (25,000 cfs) is much larger than the breach peak (6,400 cfs), a failure at the spillway would cause insignificant inundation downstream. A breach east of the spillway would be impossible as the ground level south of the dam is higher than the spillway.

East Boundary

It is estimated that no flood waters will spread east of Santa Anita Wash because: a) a breach east of the spillway is impossible and b) the large zero freeboard capacity of the wash will contain any water reaching it from the west.

West Boundary

Highland Oaks Avenue is assumed to be the conservative west boundary south to the Sierra Madre Wash confluence with Santa Anita Wash because of the following reasons:

a. The houses on the east side of Highland Oaks Avenue are 20± feet higher than the spreading grounds 800± feet downstream of the dam.

b. From 800± feet downstream of the dam to the confluence, some houses on the east side of Highland Oaks Avenue could get flooded, but the houses on the west side are 8 to 10 feet above the street.

c. A small amount of water will reach the confluence as a result of the 6,400 cfs peak discharge, 3,000 to 3,500 cfs will be taken by the channel, and a great deal will be taken by the spreading grounds.

d. The zero freeboard capacity of Sierra Madre Wash at the confluence is 4,800 cfs which is much larger than the flow spreading overland through the spreading grounds.

Sierra Madre Wash is, therefore, the south boundary.

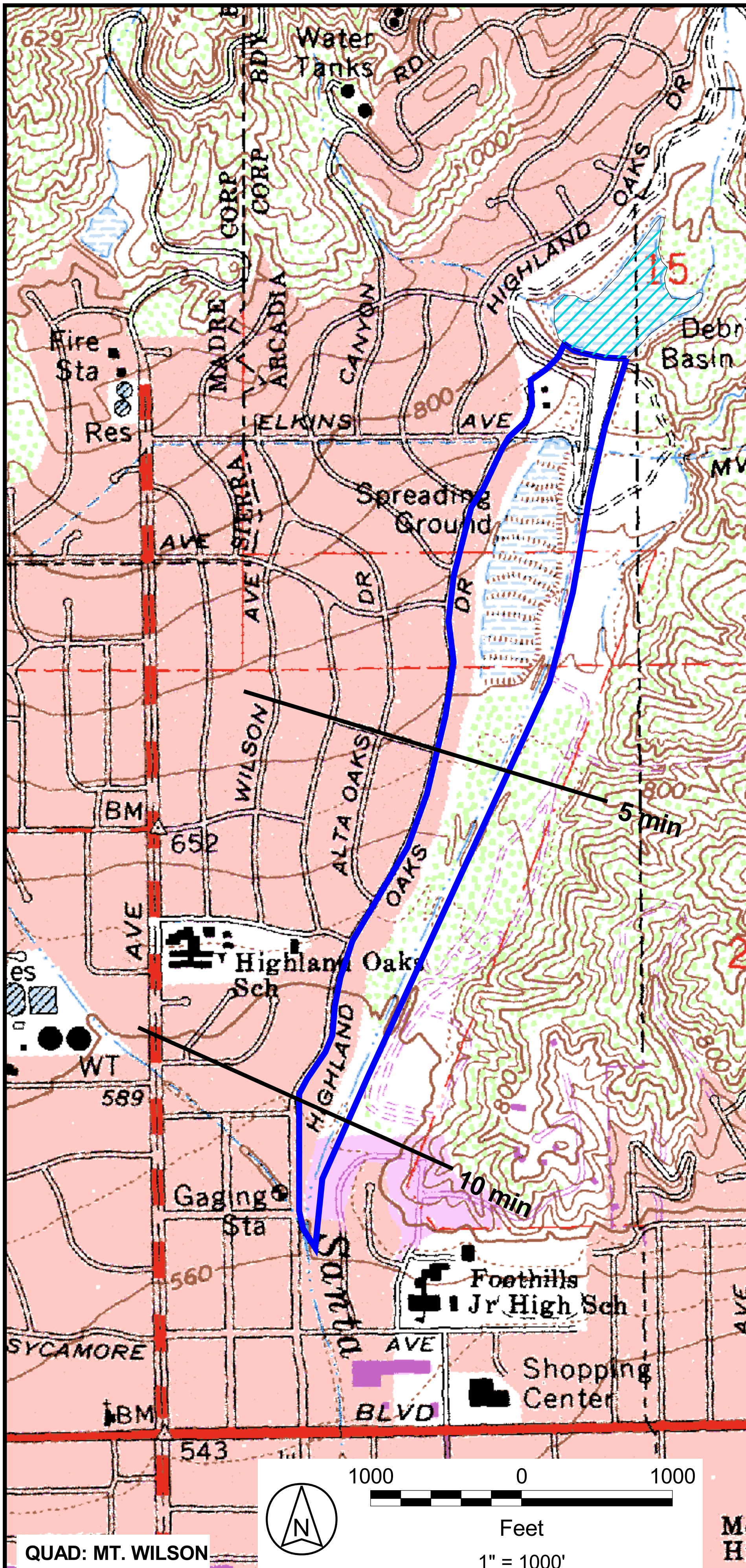
J. C. Lord
Hydraulics and Hydrology Section
Extension 74243

JCL:dms

Santa Anita Debris Basin Inundation area:

Affected Parcels (Residential with Improvement Value per Assessor): 62

Total Improvement Value = $ 14.7 M (2003 LA County Assessor)



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Very conservative assumptions were made as to the extent and rapidity of failure and as to the probable routes that the flow could follow. The inundation boundary shown on this map encompasses all probable routes that a flood flow might follow after it leaves the canyon mouth. The flow would not necessarily cover the entire area within the designated boundary.

This map is considered to be strictly a contingency measure and does not imply in any way that the dam is unsafe.

THE USE OF THIS MAP FOR PURPOSES OTHER THAN THAT FOR WHICH IT IS INTENDED IS NOT RECOMMENDED.

NOTE: This is a reproduction of the original inundated area boundary determined by the Los Angeles County Flood Control District and dated January 1974.

LEGEND

Flooded Area Boundary

Reservoir

Time Between Dam Failure and Arrival of First Water

INUNDATED AREA

SANTA ANITA DEBRIS BASIN

APPENDIX 7-B

FRAM Model (Storm Events)

FRAM Model (Storm Events)

Assumptions:

Without Project –
Less than 50-year storm would not cause dam failure due to overtopping and erosion of abutments
50-year frequency storm will cause dam failure due to overtopping and erosion of abutments.
PMP event would cause same damage

With Project –
50-year frequency storm and less will not cause flooding damage
PMP event would cause flooding damage (approx 6.5% of damage failure)

Inputs:
Resident data from inundation area (Appendix7-A) updated into 2009 dollars
Commercial data from inundation area (Appendix 7-A) updated into 2009 dollars (including Institutional)
Industrial data from inundation area (Appendix 7-A) updated into 2009 dollars

Used 50% of building costs for content costs

Did not take into account road, commerce, loss of life impacts. Only building and content costs.

Return to Menu

Project Name: Santa Anita Stormwater Flood Management and Seismic Strengthening Project

Cost of Project: $ 40,000,000

Description: The Dam can not handle a Maximum Credible Earthquake due to seismic deficiency and the spillway can not pass the Probable Maximum Flood as required by DSOD. The main spillways have a capacity of 1,376 cfs, which is not adequate to accommodate the Capital Flood (50-frequency storm) inflow of 9,700 cfs or the runoff resulting from the PMP of 26,100 cfs. If a significant storm event were to occur which exceeds the spillway capacity of the Dam, the uncontrolled overtopping of the Dam by stormwater runoff could erode the abutments or undermine the Dam, resulting in a dam failure.

Number of Events Modeled: 5

	Without Project						With Project					
	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
Average Return Interval (ARI)	5	10	25	50	10000		5	10	25	50	10000	
Annual Probability of Exceedance	0.200	0.100	0.040	0.020	0.000	#DIV/0!	0.200	0.100	0.040	0.020	0.000	#DIV/0!
Probability of Levee Failure	0.00	0.00	0.00	1.00	1.00		0.00	0.00	0.00	0.00	1.00	
Water Surface Elevation - channel (f)												
Flood Warning Time (hours)												
Flood Experience	N	N	N	N	N		N	N	N	N	N	
Period of Inundation (days)												
HEC-FIA DATA INPUTS	Y											
Residential Structural Damages ($)	0	0	0	2,399,787,000	2,399,787,000		0	0	0	0	115,986,155	
Residential Contents Damages ($)	0	0	0	1,199,893,500	1,199,893,500		0	0	0	0	77,993,078	
Residential Debris & Cleanup ($)												
Commercial Structural Damages ($)	0	0	0	507,546,000	507,546,000		0	0	0	0	32,990,490	
Commercial Contents Damages ($)	0	0	0	253,773,000	253,773,000		0	0	0	0	16,495,245	
Commercial Debris & Cleanup ($)												
Industrial Structural Damages ($)	0	0	0	87,399,000	87,399,000		0	0	0	0	5,680,935	
Industrial Contents Damages ($)	0	0	0	43,699,500	43,699,500		0	0	0	0	2,840,468	
Industrial Debris & Cleanup ($)												
Agricultural Structural Damages ($)	0	0	0	0	0		0	0	0	0	0	
Agricultural Contents Damages ($)	0	0	0	0	0		0	0	0	0	0	
Agricultural Debris & Cleanup ($)												
Residential Properties												
Ratio Depreciated Value to Replacement Value												
Average Flood depth above ground level (f)												
Rural - Res: Homesteads												
Rural - Other: Barns, sheds												
Urban Res. Single story (no base)												
Urban Res: Single story (basement)												
Urban Res. Two plus story (no base)												
Urban Res. Two plus story (basement)												
Mobile home												
Commercial Properties												
Ratio Depreciated Value to Replacement Value												
Average Flood depth above ground level (f)												
low value — building area inundated (sq.f)												
medium value — building area inundated (sq.f)												
high value — building area inundated (sq.f)												
Industrial Properties												
Ratio Depreciated Value to Replacement Value												
Average Flood depth above ground level (f)												
low value — building area inundated (sq.f)												
medium value — building area inundated (sq.f)												
high value — building area inundated (sq.f)												
Agricultural Production												
Corn — ac												
Rice — ac												
Walnuts — ac												
Almonds — ac												
Cotton — ac												
Tomatoes — ac												
Wine Grapes — ac												
Alfalfa — ac												
Pasture — ac.												
Safflower — ac												
Sugar Beets — ac												
Beans — ac												
Other — ac												
Roads												
length of arterial roads inundated (miles)												
length of major roads inundated (miles)												
length of minor roads inundated (miles)												
length of unsealed roads inundated (miles)												

Extrapolate Y-intercept: N

Summary of Cost-Benefit Analysis

Return to Menu

Project Name:	**Santa Anita Stormwater Flood Management and Seismic Strengthening Project**	
Description	The Dam can not handle a Maximum Credible Earthquake due to seismic deficiency and the spillway can not pass the Probable Maximum Flood as required by DSOD. The main spillways have a capacity of 2,900 cfs, which is not adequate to accommodate the Capital Flood (50-frequency storm) inflow of 9,700 cfs or the runoff resulting from the PMP of 26,100 cfs. If a significant storm event were to occur which exceeds the spillway capacity of the Dam, the uncontrolled overtopping of the Dam by stormwater runoff could erode the abutments or undermine the Dam, resulting in a dam failure.	
Proposed project capital cost:	$ 40,000,000	[Note: construction costs which are assumed to occur in one year.]
Change in annual O&M costs	$	[Note: the change in annual O&M costs compared to without project condit
PV of future O&M costs.	$	(at 6% discount rate over 50 years)
PV of future costs	$ 40,000,000	[Note the sum of capital costs plus the PV of O&M costs]

Benefits

	Actual	Potential	
EAD without project	$ 162,838,553	$ 168,453,675	[Note for stormwater projects use "Potential" damage which ignores st
EAD with project	$ 3,043,309	$ 3,165,579	
Annual Benefit:	$ 159,795,243	$ 165,288,096	
PV of Future Benefits:	$ 2,518,670,351	$ 2,605,247,937	(at 6% discount rate over 50 years)

Cost-Benefit Analysis

	Actual	Potential	
Net Present Value (NPV)	$ 2,478,670,351	$ 2,565,247,937	(at 6% discount rate over 50 years)
Benefit:Cost Ratio	62.967	65.131	

NPV Sensitivity to Discount Rate:

	Actual	Potential
4%	$ 3,392,750,911	$ 3,510,749,398
5%	$ 2,877,210,045	$ 2,977,487,164
6%	$ 2,478,670,351	$ 2,565,247,937
7%	$ 2,165,293,608	$ 2,241,099,081
8%	$ 1,914,852,651	$ 1,982,049,387

Residential Buildings

	Without Project						With Project					
	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
ARI:	5	10	25	50	10000	0	5	10	25	50	10000	0
Probability of Levee Failure	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Flood depth above ground level (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Buildings Inundated (no.)												
Rural - Res. Homesteads	0	0	0	0	0	0	0	0	0	0	0	0
Rural - Other Barns, sheds	0	0	0	0	0	0	0	0	0	0	0	0
Urban Res. Single story (no base)	0	0	0	0	0	0	0	0	0	0	0	0
Urban Res. Two plus story (no base)	0	0	0	0	0	0	0	0	0	0	0	0
Mobile home	0	0	0	0	0	0	0	0	0	0	0	0
Structural Damages												
Rural - Res. Homesteads	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Rural - Other Barns, sheds	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Urban Res. Single story (no base)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Urban Res Two plus story (no base)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mobile home	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Structual Damages HEC-FIA	$ -	$ -	$ -	$ 2,399,787,000	$ 2,399,787,000	$ -	$ -	$ -	$ -	$ -	$ 115,986,155	$ -
Total Structural Damages	$ -	$ -	$ -	$ 2,399,787,000	$ 2,399,787,000	$ -	$ -	$ -	$ -	$ -	$ 115,986,155	$ -
Content Damages												
Rural - Res Homesteads	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Rural - Other Barns, sheds	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Urban Res Single story (no base)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Urban Res. Two plus story (no base)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mobile home	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Contents Damage HEC-FIA	$ -	$ -	$ -	$ 1,199,893,500	$ 1,199,893,500	$ -	$ -	$ -	$ -	$ -	$ 77,993,078	$ -
Actual:Potential Ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Total Contents Damages. Actual	$ -	$ -	$ -	$ 1,079,904,150	$ 1,079,904,150	$ -	$ -	$ -	$ -	$ -	$ 70,193,770	$ -
Total Contents Damages Potential	$ -	$ -	$ -	$ 1,199,893,500	$ 1,199,893,500	$ -	$ -	$ -	$ -	$ -	$ 77,993,078	$ -
Clean-Up/ Other Costs												
External	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Cleanup	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Other Costs HEC-FIA	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Total Other Costs. Potential	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Sum Actual Damages	$ -	$ -	$ -	$ 3,479,691,150	$ 3,479,691,150	$ -	$ -	$ -	$ -	$ -	$ 186,179,925	$ -
Sum Potential Damages	$ -	$ -	$ -	$ 3,599,680,500	$ 3,599,680,500	$ -	$ -	$ -	$ -	$ -	$ 193,979,233	$ -
Total Actual Damage with levee failure ($):	$ -	$ -	$ -	$ 3,479,691,150	$ 3,479,691,150	$ -	$ -	$ -	$ -	$ -	$ 186,179,925	$ -
Total Potential Damage with levee failure ($):	$ -	$ -	$ -	$ 3,599,680,500	$ 3,599,680,500	$ -	$ -	$ -	$ -	$ -	$ 193,979,233	$ -
Indirect Actual Damage	$ -	$ -	$ -	$ 869,922,788	$ 869,922,788	$ -	$ -	$ -	$ -	$ -	$ 46,544,981	$ -
Indirect Potential Damage	$ -	$ -	$ -	$ 899,920,125	$ 899,920,125	$ -	$ -	$ -	$ -	$ -	$ 48,494,808	$ -

Commercial & Industrial Buildings

	Without Project						With Project					
	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6
ARI:	5	10	25	50	10000	0	5	10	25	50	10000	0
Probability of Levee Failure	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Commercial												
'Flood depth above ground level (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
low building size	0	0	0	0	0	0	0	0	0	0	0	0
medium building size	0	0	0	0	0	0	0	0	0	0	0	0
high building size	0	0	0	0	0	0	0	0	0	0	0	0
Industrial												
'Flood depth above ground level (ft)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
low building size	0	0	0	0	0	0	0	0	0	0	0	0
medium building size	0	0	0	0	0	0	0	0	0	0	0	0
high building size	0	0	0	0	0	0	0	0	0	0	0	0
Structural Damages												
Commercial												
low	$ -	$ -	$ -	$	$ -	$ -	$ -	$ -	$ -	$ -	$	$ -
medium	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$	$
high	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$	$
Commercial HEC-FIA	$ -	$ -	$ -	$ 507,546,000	$ 507,546,000	$ -	$ -	$ -	$ -	$ -	$ 32,990,490	$ -
Industrial												
low	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
medium	$ -	$ -	$ -	$ -	$	$ -	$ -	$ -	$ -	$ -	$ -	$ -
high	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Industrial HEC-FIA	$ -	$ -	$ -	$ 87,399,000	$ 87,399,000	$ -	$ -	$ -	$ -	$ -	$ 5,680,935	$ -
Total Structural Damages	$ -	$ -	$ -	$ 594,945,000	$ 594,945,000	$ -	$ -	$ -	$ -	$ -	$ 38,671,425	$ -
Contents Damages												
Commercial												
low	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
medium	$ -	$ -	$ -	$	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
high	$ -	$ -	$ -	$ -	$	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Commercial HEC-FIA	$ -	$ -	$ -	$ 253,773,000	$ 253,773,000	$ -	$ -	$ -	$ -	$ -	$ 16,495,245	$ -
Industrial												
low	$ -	$ -	$ -	$ -	$	$ -	$ -	$ -	$ -	$ -	$ -	$ -
medium	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
high	$ -	$ -	$ -	$ -	$ -	$	$ -	$ -	$ -	$ -	$ -	$ -
Industrial HEC-FIA	$ -	$ -	$ -	$ 43,699,500	$ 43,699,500	$ -	$ -	$ -	$ -	$ -	$ 2,840,468	$ -
Actual:Potential Ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Total Contents Damages: Actual	$ -	$ -	$ -	$ 267,725,250	$ 267,725,250	$ -	$ -	$ -	$ -	$ -	$ 17,402,142	$ -
Total Contents Damages: Potential	$ -	$ -	$ -	$ 297,472,500	$ 297,472,500	$ -	$ -	$ -	$ -	$ -	$ 19,335,713	$ -
Clean-up/ Other Costs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Clean-Up/ Other Costs: HEC-FIA	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Sum Actual Damages	**$ -**	**$ -**	**$ -**	**$ 862,670,250**	**$ 862,670,250**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 56,073,567**	**$ -**
Sum Potential Damages	**$ -**	**$ -**	**$ -**	**$ 892,417,500**	**$ 892,417,500**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 58,007,138**	**$ -**
Total Damage with levee failure ($):	**$ -**	**$**	**$**	**$ 862,670,250**	**$ 862,670,250**	**$**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 56,073,567**	**$**
Total Damage with levee failure ($):	**$ -**	**$**	**$**	**$ 892,417,500**	**$ 892,417,500**	**$**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 58,007,138**	**$**
Indirect Actual Damages	$ -	$ -	$ -	$ 215,667,563	$ 215,667,563	$ -	$ -	$ -	$ -	$ -	$ 14,018,392	$ -
Indirect Potentail Damages	$ -	$ -	$ -	$ 223,104,375	$ 223,104,375	$ -	$ -	$ -	$ -	$ -	$ 14,501,785	$ -

Calculation of Without Project EAD

	Event 1	Event 2	Event 3	Event 4	Event 5	[illegible]	Y Intercept
Average Recurrence Interval (ARI)	5	10	25	50	10000	0	
AEP	0.200	0.100	0.040	0.020	0.000	#DIV/0!	0
Actual Damage to Residential Buildings ($)	$ -	$ -	$ -	$ 3,479,691,150	$ 3,479,691,150	$ -	
Potential Damage to Residential Buildings ($)	$ -	$ -	$ -	$ 3,599,680,500	$ 3,599,680,500	$ -	
Actual Damage to Commercial/Industrial Buildings ($)	$ -	$ -	$ -	$ 862,670,250	$ 862,670,250	$ -	
Potential Damage to Commercial/Industrial Buildings ($)	$ -	$ -	$ -	$ 892,417,500	$ 892,417,500	$ -	
Damage to Agriculture ($)	$ -	$ -	$ -	$ -	$ -	$ -	
Damage to Roads ($)	$ -	$ -	$ -	$ -	$ -	$ -	
Actual Indirect Costs	$ -	$ -	$ -	$ 1,085,590,350	$ 1,085,590,350	$ -	
Potential Indirect Costs	$ -	$ -	$ -	$ 1,123,024,500	$ 1,123,024,500	$ -	
Special Cases	$ -	$ -	$ -	$ -	$ -	$ -	
Total Actual Damages	$ -	$ -	$ -	$ 5,427,951,750	$ 5,427,951,750	$ -	$5,427,951,750
Total Potential Damages	$ -	$ -	$ -	$ 5,615,122,500	$ 5,615,122,500	$ -	$5,615,122,500
EAD (Actual)	$ 162,838,553						
EAD (Potential)	$ 168,453,675						

Actual Damages

Calculation of With Project EAD

	Event 1	Event 2	Event 3	Event 4	Event 5	Event 6	
Average Recurrence Interval (ARI)	5	10	25	50	10000	0	
AEP	0.200	0.100	0.040	0.020	0.000	#DIV/0!	0
Actual Damage to Residential Buildings ($)	$ -	$ -	$ -	$ -	$ 186,179,925	$ -	
Potential Damage to Residential Buildings ($)	$ -	$ -	$ -	$ -	$ 193,979,233	$ -	
Actual Damage to Commercial/Industrial Buildings ($)	$ -	$ -	$ -	$ -	$ 56,073,567	$ -	
Potential Damage to Commercial/Industrial Buildings ($)	$ -	$ -	$ -	$ -	$ 58,007,138	$ -	
Damage to Agriculture ($)	$ -	$ -	$ -	$ -	$ -	$ -	
Damage to Roads ($)	$ -	$ -	$ -	$ -	$ -	$ -	
Actual Indirect Costs	$ -	$ -	$ -	$ -	$ 60,563,373	$ -	
Potential Indirect Costs	$ -	$ -	$ -	$ -	$ 62,996,593	$ -	
Special Cases	$ -	$ -	$ -	$ -	$ -	$ -	
Total Actual Damages	$ -	$ -	$ -	$ -	$ 302,816,865	$ -	$ 302,816,865
Total Potential Damages	$ -	$ -	$ -	$ -	$ 314,982,964	$ -	$ 314,982,964

EAD (Actual)	$ 3,043,309
EAD (Potential)	$ 3,165,579

Actual Damages

APPENDIX 7-C

Hydrologic Runs Santa Anita Dam

2- , 5-, 10-, 25-, 50-year

Hydrologic Run through Santa Anita Dam

Using theoretical storms for 2-, 5-, 10-, 25-, and 50-year frequency storms.

Excel Spreadsheet contains actual data

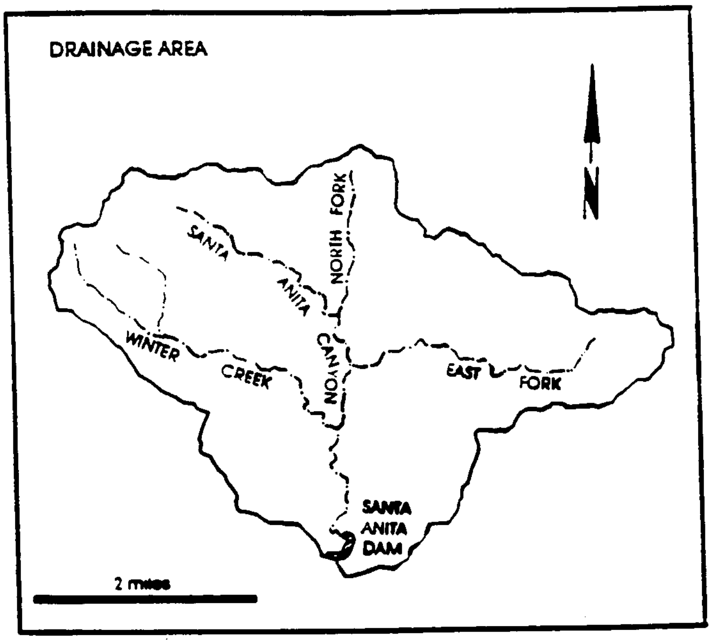
Runs for:
Sluice Gate 100% open
All Valves open and Sluice Gate Open
All Valves open and Sluice Gate Closes (i.e. blocked)

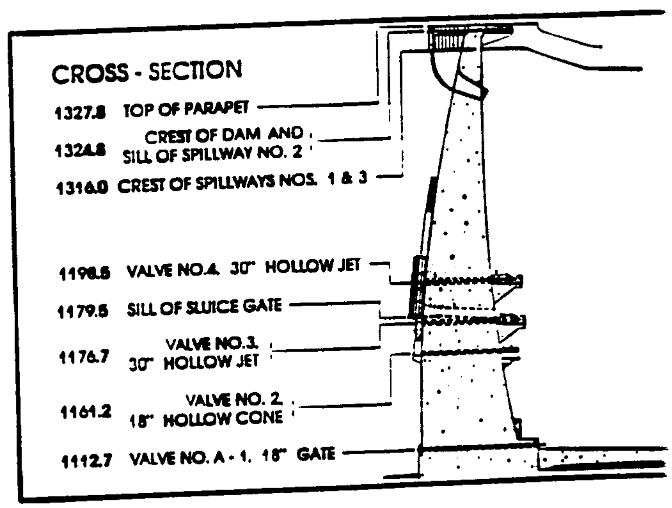
Only Sluice Gate Open				
Storm Frequency	Max Inflow (cfs)	Max Outflow (cfs)	Max WSE (ft)	Max Storage (ac-ft)
2-YR	3099.0	736.6	1301.7	643.8
5-YR	5008.0	4025.3	1325.4	969.0
10-YR	6263.0	6105.7	1327.8	1005.1
25-YR	7842.0	7652.7	1329.3	1029.2
50-YR	9018.0	9002.1	1330.6	1040.2

All Valves Open, Sluice Gate Open				
Storm Frequency	Max Inflow (cfs)	Max Outflow (cfs)	Max WSE (ft)	Max Storage (ac-ft)
2-YR	3099.0	1224.8	1284.6	453.7
5-YR	5008.0	2944.8	1320.1	889.0
10-YR	6263.0	5450.3	1326.3	982.4
25-YR	7842.0	7651.4	1328.5	1017.3
50-YR	9018.0	8801.1	1329.7	1035.2

Valves Open, Sluice Gate Closed				
Storm Frequency	Max Inflow (cfs)	Max Outflow (cfs)	Max WSE (ft)	Max Storage (ac-ft)
2-YR	3099.0	685.0	1312.6	784.1
5-YR	5008.0	4651.2	1326.3	983.0
10-YR	6263.0	6107.0	1327.9	1006.4
25-YR	7842.0	7652.8	1329.4	1030.5
50-YR	9018.0	8907.5	1330.6	1040.2

SANTA ANITA DAM
AND RESERVOIR





PURPOSE - Flood Control and Conservation.
DATE CONSTRUCTED - Started October 1924. Completed March 1927.
LOCATION - 2.5 miles north of Arcadia
DRAINAGE AREA - 10.8 square miles.
CAPACITY - 836 acre - feet.
SPILLWAY ELEVATION - 1,316.0 feet.

TITLE CARD(S)
TT FLOOD FLOW FREQUENCY ANALYSIS PROGRAM
TT FITTING THE LOG-PEARSON TYPE III DIST
TT DAM INFLOW, SANTA ANITA DAM

FINAL RESULTS
-PLOTTING POSITIONS-SANTA_ANITA

EVENTS ANALYZED				ORDERED EVENTS			
MON	DAY	YEAR	FLOW,CFS	RANK	WATER YEAR	FLOW,CFS	WEIBULL PLOT POS
1	19	1933	390.	1	1969	5500.	.0167
1	1	1934	800.	2	1938	5140.	.0333
4	8	1935	449.	3	1943	3100.	.0500
2	12	1936	228.	4	1966	1920.	.0667
2	6	1937	313.	5	1967	1520.	.0833
3	2	1938	5140.	6	1962	1460.	.1000
12	19	1938	159.	7	1973	1350.	.1167
1	8	1939	378.	8	1954	1240.	.1333
3	4	1941	300.	9	1983	1197.	.1500
12	29	1941	53.	10	1993	909.	.1667
1	23	1943	3100.	11	1992	863.	.1833
2	22	1944	813.	12	1952	837.	.2000
11	11	1944	303.	13	1944	813.	.2167
12	23	1945	492.	14	1934	800.	.2333
11	20	1946	382.	15	1971	674.	.2500
4	28	1948	41.	16	1959	622.	.2667
1	20	1949	32.	17	1958	618.	.2833
12	18	1949	115.	18	1956	569.	.3000
1	11	1951	10.	19	1946	492.	.3167
1	16	1952	837.	20	1935	449.	.3333
12	1	1952	153.	21	1991	417.	.3500
1	24	1954	1240.	22	1933	390.	.3667
11	11	1954	173.	23	1947	382.	.3833
1	26	1956	569.	24	1939	378.	.4000
2	23	1957	122.	25	1963	368.	.4167
4	3	1958	618.	26	1937	313.	.4333
1	6	1959	622.	27	1945	303.	.4500
2	1	1960	16.	28	1941	300.	.4667
1	26	1961	65.	29	1974	280.	.4833
2	11	1962	1460.	30	1936	228.	.5000
2	9	1963	368.	31	1982	213.	.5167
4	1	1964	53.	32	1970	208.	.5333
4	9	1965	130.	33	1977	200.	.5500
12	29	1965	1920.	34	1955	173.	.5667
12	6	1966	1520.	35	1968	165.	.5833
11	19	1967	165.	36	1939	159.	.6000

FINAL RESULTS
-PLOTTING POSITIONS-SANTA_ANITA

EVENTS ANALYZED				ORDERED EVENTS			
MON	DAY	YEAR	FLOW,CFS	RANK	WATER YEAR	FLOW,CFS	WEIBULL PLOT POS
1	25	1969	5500.	37	1953	153.	.6167
2	28	1970	208.	38	1981	147.	.6333
11	29	1970	674.	39	1984	142.	.6500
12	24	1971	99.	40	1965	130.	.6667
2	11	1973	1350.	41	1957	122.	.6833
1	7	1974	280.	42	1989	119.	.7000
3	6	1975	54.	43	1990	117.	.7167
3	1	1976	101.	44	1950	115.	.7333
1	3	1977	200.	45	1985	102.	.7500
1	29	1981	147.	46	1976	101.	.7667
3	17	1982	213.	47	1972	99.	.7833
3	2	1983	1197.	48	1986	89.	.8000
12	25	1983	142.	49	1988	87.	.8167
12	19	1984	102.	50	1961	65.	.8333
1	30	1986	89.	51	1975	54.	.8500
1	5	1987	11.	52	1964	53.	.8667
1	17	1988	87.	53	1942	53.	.8833
2	4	1989	119.	54	1948	41.	.9000
2	17	1990	117.	55	1949	32.	.9167
3	1	1991	417.	56	1994	19.	.9333
2	11	1992	863.	57	1960	16.	.9500
1	7	1993	909.	58	1987	11.	.9667
3	24	1994	19.	59	1951	10.	.9833

FILENAME: S-ANITA.DAT (STATION SKEW ONLY)
FINAL RESULTS
-FREQUENCY CURVE-SANTA_ANITA

FLOW, CFS COMPUTED	FLOW, CFS EXPECTED PROBABILITY	EXCEEDANCE PROBABILITY		CONFIDENCE LIMITS .05 LIMIT	CONFIDENCE LIMITS .95 LIMIT
12200.	14700.	.002	500YR	26500.	6780.
8280.	9540.	.005	200YR	16900.	4800.
5980.	6690.	.010	100YR	11600.	3600.
4180.	4550.	.020	50YR	7660.	2610.
2800.	2980.	.040	25YR	4830.	1820.
1490.	1540.	.100	10YR	2360.	1030.
818.	834.	.200	5YR	1210.	588.
254.	254.	.500	2YR	345.	187.
76.	75.	.800		106.	52.
40.	39.	.900		58.	25.
23.	22.	.950		36.	14.
8.	7.	.990		14.	4.

FREQUENCY CURVE STATISTICS		STATISTICS BASED ON	
MEAN LOGARITHM	2.3942	HISTORIC EVENTS	0
STANDARD DEVIATION	.6132	HIGH OUTLIERS	0
COMPUTED SKEW	-.0970	LOW OUTLIERS	0
GENERALIZED SKEW	-99.0000	ZERO OR MISSING	0
ADOPTED SKEW	-.0970	SYSTEMATIC EVENTS	59

APPENDIX 7-D

Big Tujunga Dam BCA Reference

BIG TUJUNGA DAM

SEISMIC RETROFIT

BENEFIT-COST ANALYSIS REPORT

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October 11, 2008

Introduction

The Big Tujunga dam is a concrete arch dam which was originally constructed in 1930 and 1931 (MWH, 2007). The dam crest is 244 feet above bedrock. The dam structure includes three elements, with a total crest length of about 830 feet:

- the concrete arch portion with a crest length of 400 feet,
- an uncontrolled ogee weir spillway with a crest length of 122 feet on the north side of the arch portion, and
- a concrete-faced earthen embankment wing wall with a length of about 308 feet, extending northwards from the spillway.

Regulated outflows are governed by valves on four outlet pipes with diameters of 12, 48, 60, and 72 inches. In addition a 60" sluice tunnel is used for sluicing sediments from the reservoir (MWH, 2007).

Unregulated flows over the spillway occur whenever the reservoir level reaches the spillway crest. Extreme flows in excess of the spillway capacity would result in unregulated flows over the dam crest and abutments.

The Big Tujunga dam, which was designed in the late 1920s, did not have an explicit seismic design criterion. However, a detailed engineering analysis of the existing dam, which established the elevation for lowering the reservoir, concluded that 0.6 g was the maximum credible earthquake that the dam could withstand (Lindvall Richter and Associates, 1975). However, subsequent concerns with the stability of the left abutment have lowered this estimate (Lilley, PE, 2007). Thus, the best available estimate of the seismic capacity of the existing dam is less than 0.6 g. This seismic capacity is substantially deficient relative to the current seismic design criteria of 1.1 g for this site.

The Big Tujunga dam does not meet the seismic safety requirements of the California Department of Water Resources Division of Safety of Dams (DSOD). DOSD has thus restricted the maximum allowable reservoir elevation to 2,213 feet, which corresponds to about 22% of the reservoir's original storage capacity.

The DSOD has also raised the Probable Maximum Flood from 86,500 cfs to 111,570 cfs. Thus, the existing dam structure has substantial deficiencies with respect to extreme floods as well as with respect to earthquakes.

Mitigation Alternatives

Given the substantial seismic and hydraulic deficiencies of the existing dam structure, the dam cannot continue to be operated at the current restricted reservoir elevation. Rather, there are three possible alternatives:

- remove the dam completely,
- convert the existing structure to a debris dam only, or
- retrofit the dam to DSOD standards.

Complete Removal of the Dam

Complete removal of the dam is not a viable option because it would not only result in loss of water storage but also substantially increase the flood risk downstream because stream flow would be completely uncontrolled.

Conversion to a Debris Dam Only

Conversion of the existing structure to a debris dam only would significantly reduce, but not completely mitigate the seismic and hydraulic risk. A debris dam would not have permanent storage. However, outflows would be limited to the maximum outlet conveyance capacity and thus reservoir levels could still rise significantly during periods of large inflows.

There are also two other significant negative attributes for conversion of the dam to a debris dam only: 1) loss of water storage, and 2) environmental impacts from loss of supplemental stream flow during dry months. The stream provides habitat to a threatened fish species, the Santa Ana Sucker, loss of the ability to supplement stream flows during dry months could result in complete loss of this species from the stream.

Despite these negative aspects, conversion of the dam to a debris dam only would meet DSOD's regulatory requirements. The cost to convert the dam to a debris dam only is estimated to be $40,950,000 (Lilley PE, 2007). In effect this cost is thus the minimum cost to make the dam compliant with the DSOD regulatory requirements and thus is conceptually equivalent to the minimum cost for code compliance for a building.

Retrofit of the Existing Dam

The retrofit of the existing dam to full compliance with DSOD's seismic and hydraulic requirements is fully described in the 100% Final Design Report (MWH, 2007). A brief synopsis is given below, quoted verbatim from the Final Design Report.

> "The new seismic rehabilitation design consists of placement of new conventional mass concrete (CMC) on the downstream face of the existing arch dam to create a new thick-arch dam. The new concrete section will have a crest thickness of 12 feet(20 feet total crest thickness, including the existing dam crest and the new concrete), a downstream slope of 0.25 to 1 (horizontal to vertical), and a base thickness of approximately 66 feet. Considering that the thickness of

> the existing dam base is 73 feet, the total base thickness of the new thick-arch dam will be approximately 140 feet and the base to height ratio will be approximately 0.6. The total volume of new concrete for the thick arch is estimated at approximately 70,000 to 80,000 cubic yards."
>
> "To accommodate a new larger PMF, a new hydraulic rehabilitation design incorporates a partial ogee crest into the central spillway for flows overtopping the dam. The spillway shape and resulting spill trajectory is designed to throw essentially the entire spill into the canyon bottom downstream and away from the toe of the dam."

The final cost of the dam retrofit is $88,533,680 (Shimmick Construction Company Inc.), the bid amount accepted by the Los Angeles County Flood Control District.

Benefit-Cost Analysis: Approach and Data Inputs

Overview: Lower-Bound Approach

There are three principal hazards which pose significant risk of dam failure: large seismic events, extreme flood events, and large landslides into the reservoir.

- The retrofit project will provide a very high level of seismic capacity, with the design basis being 1.1 g, compared to 0.6 g or less for the existing dam.

- The retrofit project will provide very high degree of protection from extreme flood events by directing overtopping flows at the PMF (or even higher) downstream into the canyon bottom away from the toe of the dam.

- The retrofit project will also provide substantial protection against landslide-induced hydraulic surges by greatly strengthening the current thin-arch dam into a thick-arch dam.

The present benefit-cost analysis considers the seismic benefits only and is thus a conservative lower-bound type analysis. Inclusion of the benefits of reduced probability of dam failure from extreme floods and from landslides into the reservoir would yield higher benefits and higher benefit-cost ratios.

The inundation area within the Tujunga Valley from the Big Tujunga dam to Foothill Boulevard has a length of about 10.5 miles. The canyon is narrow over most of the reach, with many sections roughly 500' to 1000' wide and nearly the entire reach less than 2000' wide. The elevation drop from the dam to Foothill Boulevard is nearly 1000'. Given these hydraulic conditions, the flows will be deep with high velocities, resulting in virtually complete damage to structures and a very high casualty rate for people within the inundation area.

For purposes of benefit-cost analysis, we assume 90% damage to buildings and contents within the inundation zone. Nearly all buildings are almost certain to be completely destroyed, but some buildings at the extreme fringe of the inundation zone may survive with less than complete damage.

The inundation times along the Tujunga Valley range from essential zero near the dam to only about 35 minutes at Foothill Boulevard. There is no automated warning system or warning sirens. Given these conditions, relatively few (if any) occupants within the inundation zone are likely to receive warning and react quickly enough to avoid inundation. If dam failure were to occur during nighttime hours the death rate would likely be nearly 100% of occupants. If dam failure were to occur during daytime hours, the death rate would be very high, but, hopefully, less than 100%.

In the spirit of this conservative, lower-bound type benefit-cost analysis, we assume an average death rate of 80%. Unfortunately, the actual death rate might well be closer to 100%.

Seismic Fragility Curves

For the as-is dam, we estimate the following seismic fragility data for the complete damage state (dam failure): median failure 0.60 g, beta 0.64 (beta is a lognormal standard deviation parameter). This is a conservative fragility estimate, because engineering staff at the Los Angeles County Department of Public Works estimated the seismic capacity of the as-is dam as less than 0.6 g. We use a higher median PGA for failure, 0.60 g, because exceeding the capacity does not necessarily result in failure. The beta of 0.64 is the typical HAZUS beta, when there is incomplete information about a facility.

For the after-mitigation dam, we estimate the median PGA for failure as 1.65 g with a beta of 0.40. The stated design basis for the retrofitted dam is 1.10 g; however, the usual design basis for International Building Code seismic provisions is deemed to provide life safety to ground motions 50% higher than the design basis. For example, a building designed per the IBC to 2/3rds of the 2% in 50 year ground motions is deemed to have an extremely low probability of collapse up to the full 2% in 50 year ground motion. The smaller beta reflects greater certainty in the seismic performance of the retrofitted dam.

For this benefit-cost analysis, we consider only the complete damage state and not consider the benefits of reducing damages to the dam for lower damage states (e.g., slight, moderate or extensive damage states as defined in HAZUS).

Furthermore, for benefit-cost analysis, we adopt a very conservative lower bound assumption that the probability of failure is nil when the reservoir level is at or below the DSOD's authorized reservoir level. Reservoir elevation data from January 1, 2002 through July 23, 2008, show that the reservoir has been above authorized levels 23.74% of the time (555 days out of a total of 2,338 days). For each PGA bin in the FEMA BCA software, we calculate the probability of failure at the PGA value corresponding to the mid-point of each bin and then take 23.74% of that probability as the actual probability of dam failure.

The above assumptions are lower bound assumptions because the probability that the dam fails when it is at or below the authorized levels is very low, but not zero.

After mitigation, we calculate the probability of failure, assuming equal probabilities 365 days per year. In reality, the after-retrofit dam will have a much lower probability of failure during low water times. Thus, the assumptions for the as-is and after retrofit conditions are both lower bound type assumptions which may significantly underestimate the actual benefits of the mitigation project.

The probabilities of failure are calculated from the FEMA Fragility Curve Calculator for the as-is and after-retrofit fragility data above. These results are shown in Table 1 on the following page.

These fragility-curve based results indicate annual probabilities of failure for the as-is and after-retrofit dam of approximately 0.00333 and 0.000172, respectively. These probabilities correspond to return periods for failure of 300 years for the as-is dam and 5,803 years for the after-retrofit dam. These return periods reflect the significant risk pose by the as-is dam and the high level of safety provided by the seismic retrofit. As noted above, these return periods are lower-bound type estimates for benefit-cost analysis; that is, the as-is-dam is likely more vulnerable than assumed and the after-retrofit dam is likely less vulnerable than assumed.

Table 1
Big Tujunga Dam Seismic Fragility Results

PGA (% g)[1]	Annual Earthquake Probability[2]	As-Is Dam				After Retrofit Dam	
		Fragility Curve Probability of Failure	Probability Reservoir Above Authorized	Combined Probability of Failure	Annual Probability of Dam Failure[3]	Fragility Curve Probability of Failure	Annual Probability of Dam Failure[3]
4-8	0.065295950	0.0161%	23.74%	0.00003810	0.00000249	0.0000	0.00000000
8-16	0.081245261	0.5956%	23.74%	0.00141393	0.00011488	0.0000	0.00000000
16-32	0.064525177	7.6114%	23.74%	0.01806953	0.00116594	0.0000	0.00000005
32-55	0.020426755	30.7667%	23.74%	0.07304013	0.00149197	0.0004	0.00000878
55-80	0.002789559	57.3007%	23.74%	0.13603195	0.00037947	0.0127	0.00003549
80-100	0.000477843	73.6809%	23.74%	0.17491852	0.00008358	0.0648	0.00003098
>100	0.000455515	86.0605%	23.74%	0.20430767	0.00009307	0.2130	0.00009701
				Total:	0.00333139	**Total:**	0.00017232
				Return Period (years):	**300**	**Return Period (years):**	**5,803**

[1] These are the PGA "bins" in the FEMA Full Data BCA Module for Seismic Projects.

[2] From FEMA Full Data BCA Module, using standard FEMA/USGS seismic data

[3] Annual probability of a given ground motion times the probability of failure if the ground motion occurs.

Benefit-Cost Analysis Data Inputs

Big Tujunga Dam Replacement Value

$150,000,000 (Lilley, 2007). The replacement value for a current-code dam was estimated based on the rehabilitation cost plus the original dam cost ($1.16 million) updated to current values. The original dam plus additions included in the rehabilitation is a reasonable approximation to a current code dam.

Building Value in Inundation Area

$54,322,000 (Lilley, 2007). Building values (excluding land values) for the 757 parcels in the inundation area were taken from January 2005 Los Angeles County Assessor's data. However, per Proposition 13, these values do not reflect current values, but rather values at the time of purchase or refinancing. More than 70% of the values were pre-2000, with many much older. The assessed values were increased by 50% to more accurately reflect current replacement values for benefit-cost analysis. Building damage given dam failure was estimated conservatively at 90% of building value.

Contents Replacement Value

$27,161,000. 50% of building replacement value. HAZUS typical value for residential and FEMA standard value for next generation BCA software. Contents damage given dam failure was estimated conservative at 90% of contents value.

Displacement Costs

$5,970,760. Displacement cost for temporary housing were estimated conservatively using typical FEMA values for displacement time, monthly rental costs, other monthly costs and one-time costs. Actual displacement costs would likely be significantly higher, thus this value is a lower-bound type estimate for benefit-cost analysis.

Data inputs and calculations for building value, contents value and displacement costs for temporary housing are summarized in Table 2 below.

Table 2
Building Value, Contents Value and Displacement Costs.

Parcels	757		
BRV	$54,322,000	$48,889,800	90% damage
BRV/SF	$150.00	estimate	
SF	362,147	estimate	
Average SF	1,449	estimate	
Number of Buildings	250	estimate	
Contents (50% BRV)	$27,161,000	$24,444,900	90% damage
Displacement Costs		Unit Costs	Total Costs
Rent/month	$1.00	per SF	$362,147
Other monthly costs	$500	per building	$125,000
One time costs	$500	per building	$125,000
Displacement Time	12	months FEMA typical "cap"	
Displacement Costs per Failure			
Rent	$4,345,760	Note: these are lower bound inputs, using above FEMA typical values, which are low.	
Other monthly	$1,500,000		
One Time	$125,000		
Total	$5,970,760		

Occupancy within Inundation Zone and Casualties

Occupany estimates for the inundation area are summarized below in Table 3.

Table 3
Occupancy within Inundation Area.

Occupancy	Weekdays			Weekends		
	Day	Evening	Nights	Day	Evening	Nights
Dwellings	414	931.5	1035	828	931.5	1035
School	506.25	0	0	0	0	0
Athletic fields	12.5	12.5	0	50	0	0
Golf/tennis	50	25	0	100	50	0
YMCA Camp	33	0				
Road Traffic, hikers, picnickers	20	5	2	30	5	2
Totals	**1035.75**	**974**	**1037**	**1008**	**986.5**	**1037**

Assume 12 months per year, except for the school. Seasonal variations included in estimates.

Residential occupancy estimates are from census data, assuming 40% occupancy during weekday days, 80% occupancy on weekend days, 90% occupancy evenings and 100% occupancy nights.

The Sunland School has an enrollment of 650 students and an estimated 25 staff. To account for a 9-month school year, these occupancies are reduced by 25% for weekdays, with no occupancy assumed at other times.

The athletic fields are assumed to host an average of 1 event per weekday day and evening and 4 events per weekend day, with no events at other time. An average attendance of 50 people (participants and spectators) for an average duration of 2 hours. Thus, for example, 1 event with 50 people for 2 hours weekdays corresponds to an average weekday occupancy of 12.5 people (8 hour day).

The golf/tennis club as an average of 150 to 200 visitors per day and about 40 staff. The occupancy estimates above are conservative, assuming that visitors average 4 or 5 hours for golf and about 2 hours for tennis and other club activities.

The occupancy of the YMCA camp is estimated at 100 people for summer weekdays only. The small occupancies for vehicle occupants, picnickers and hikers are lower-bound type estimates.

With the above, partially placeholder inputs, the average 24/7/365 occupancy is 1018.70 people, as calculated from the above occupancy data entered into the FEMA Full Data BCA software. The average occupancy calculation is shown below in Table 4.

Table 4
Average (24/7/365) Occupancy Calculations

Building Occupancy

	Weekdays			Weekends		
	Day	Evening	Night	Day	Evening	Night
Occupants	1035.75	974	1037	1008	987	1037
Days / Week	5	5	5	2	2	2
Hours / Day	9	6	9	9	6	9
Months / Year	12	12	12	12	12	12
Average Occupancy (24 hours, 7 days / week)						1018.70

For benefit-cost analysis, we use FEMA's 2008 statistical value of life, which is $3,332,958. With an estimated 80% death rate, the average death total is about 815and the corresponding economic value is $2,716, 227,452 (about $2.7 billion).

Value of Water Storage

At the dam's current restricted operating level, the average annual water storage is approximately 2,923 acre-feet. After retrofit, the average annual water storage will increase by approximately 4,500 acre-feet. At the current (as of January 2009) Metropolitan Water District wholesale rate of $412 per acre-foot, the annual value of water lost by the current reservoir restrictions is $1,854,000.

Benefit-Cost Analysis Results

Using the above seismic fragility estimates and values for the various categories of damages and losses considered yields the total damages and losses per dam failure event shown in Table 5. The total damages and losses are about $2.6 billion, with about 90% from the statistical value of expected deaths.

Table 5
Scenario Damages and Losses per Dam Failure Event

Dam Replacement	$150,000,000
Building Damages	$48,889,800
Contents Damages	$24,444,900
Displacement	$5,970,760
Deaths	$2,716,227,452
Subtotal	**$2,945,532,912**

Taking into account the annual probabilities for failure (return periods) of the dam under as-is and after-retrofit conditions (cf. Table 1 above), the annualized damages for the as-us and after-retrofit conditions are shown in Table 6.

Table 6
Annualized Damages and Losses

Results	As-Is	After-Retrofit	Annual Benefits
Return Period for Failures	300	5,803	N/A
Annualized Damages	$9,812,730	$507,562	$9,305,168
Annual Water Loss Value	$1,854,000	$0.00	$1,854,000
Totals	$11,666,730	$507,562	$11,159,168

Benefit-cost results are shown below in Table 7.

Table 7
Benefit-Cost Results

Annual Benefits	**$11,159,168**
Present Value Coefficient[1]	**14.27**
Net Present Value of Benefits	**$159,241,327**
Project Cost	**$88,533,680**
Benefit-Cost Ratio	**1.799**

[1] Present Value Coefficient for 7% discount rate and 100-year project useful lifetime from FEMA Seismic BCA Technical Manual

The conservative, lower-bound type inputs into this benefit-cost analysis yield a BCR of 1.799 Thus, this mitigation project is demonstrably cost effective with over $159 million in benefits for a project cost of about $88.5 million.

The benefit-cost results presented above are conservative lower-bound results in many ways:

1) The analysis considers only seismic risk and does not consider the risk of dam failure from extreme flood events or large landslides into the reservoir. If extreme floods and landslides each have return periods for failure of 1,000 years, then the calculated return period for failure of the as-is dam would decrease from 300 years to about 187 years. In this case, the benefit-cost ratio would be about 2.75.
2) The damage and loss estimates for the categories included in the BCR are conservative and likely underestimate the actual damages and losses, with a commensurate underestimate of the benefits.
3) Several categories of significant damages and losses were not considered in the analysis; including these categories would raise the calculated benefits:
    a. Disruption time – economic impacts,
    b. Debris removal, valley restoration, emergency response and emergency management costs,
    c. Other damages to landscaping, vehicles and outbuildings.
    d. Infrastructure damage to roadways, bridges, and utilities within the inundation area,
    e. Damage to the major bridges of I-210 and Foothill Boulevard, and
    f. The economic impacts of road/bridge closures.
    g. Loss of flood protection for residents within Big Tujunga Creek and reduction in flood protection for the Los Angeles River system downstream.

Considering all of the above lower-bound type assumptions, a complete best-data benefit-cost analysis would likely yield a BCR in the range of approximately 2.5 to 3.0, considering seismic benefits only. Thus, this mitigation project is likely even more cost-effective than demonstrated by the present conservative benefit-cost analysis.

Benefit-Cost Analysis Using FEMA BCA Software

The above BCA can also be done using the FEMA BCA software. The FEMA "Limited-Data" BCA module can be used for any hazard, as long as a damage-frequency relationship can be established.

For this BCA, we use the return periods for dam failure (as-is) and after-mitigation shown above in Table 1 and the damages and losses shown in Tables 6 (dam replacement, building damages, contents damages, displacement costs, and deaths) and Table 7 (annual water loss value). *To use, the FEMA BCA module, two analyses have to be run because the module automatically interpolates between entries at different frequencies. Thus, if the annual value of water loss is entered for a "1-year" event, the module (incorrectly) interpolates this value for events up the 300-year event where dam failure is assumed, which is incorrect for the value of water lost calculations.*

The total benefits for this project are thus the sum of the benefits for the two BCA runs summarized below: Big-T BCA-LD-01.xls and Big-T-LD-BCA-02.xls.

Table 8
Benefits Calculation: Avoided Damages, Displacement Costs and Deaths

SUMMARY OF BENEFITS AND COSTS	Expected Annual	Present Value
Expected Annual Damages Before Mitigation	$9,812,730	$140,020,306
Expected Annual Damages After Mitigation	$507,309	$7,238,921
Expected Avoided Damages After Mitigation (BENEFITS)	$9,305,421	$132,781,384
PROJECT COSTS	$88,533,680	
PROJECT BENEFITS	$132,781,384	
BENEFITS MINUS COSTS	$44,247,704	
BENEFIT-COST RATIO	1.50	

Table 9
Benefits-Calculation: Avoided Loss of Water Value

SUMMARY OF BENEFITS AND COSTS

	Expected Annual	Present Value
Expected Annual Damages Before Mitigation	$1,854,000	$26,455,188
Expected Annual Damages After Mitigation	$0	$0
Expected Avoided Damages After Mitigation (BENEFITS)	$1,854,000	$26,455,188

PROJECT COSTS	$88,533,680
PROJECT BENEFITS	$26,455,188
BENEFITS MINUS COSTS	($62,078,492)
BENEFIT-COST RATIO	0.30

Table 10
Total Benefits

Project Costs	$88,533,680
Project Benefits	$159,236,572
Benefits Minus Costs	$70,702,892
Benefit-Cost Ratio	**1.799**

The very minor differences between the total benefits calculated above in Table 7 and the results in Table 10 using the FEMA BCA software result from minor rounding errors in the calculations; these differences are inconsequential.

References

Lilley, Keith (2007). Los Angeles County Public Works Department. Notes, comments and calculations for Big Tujunga Dam.

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MWH (2007), Final 100% Seismic Design, Big Tujunga Dam Seismic Rehabilitation and Spillway Modification Project